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EXPERIMENTAL RFQ AS INJECTOR TO THE CERN LINAC I*

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Summary

Since the successful development and testing of a radio-frequency quadrupole (RFQ) prototype at Los Alamos, the use of RFQs as injectors to the CERN linacs is being envisaged. As a pilot project, a 202.56-MHz RFQ for Linac I (Old Linac) is being built in close collaboration between Los Alamos and CERN. We intend to complete this project in about 15 months, a time scale imposed by other CERN programs. The CERN RFQ is based on the Los Alamos proven design approach, but will have to meet requirements of the existing CERN environment. The design characteristics of this accelerator are described, and some conclusions based on model work at CERN are given.

Introduction

The successful proof-of-principle test of an RFQ at Los Alamos,[1-3] announced at the 1980 International Accelerator Conference,[4] was the trigger for launching a collaboration between CERN and Los Alamos on this project. The aim of this joint development effort is to design and build an RFQ as a preaccelerator for CERN's Linac I, where it has to fulfill the stringent requirements generally imposed on an injector. We hope that this project can be taken as a model for an RFQ that can later replace the 750-kV Cockcroft-Walton and the low-energy beam transport on Linac II. In general, it would serve to refine and to further test the validity of the design techniques, and would provide the CERN staff with insight that could be useful for future potential applications for the RFQ.

Description of The Project

The schematic layout of the CERN RFQ project is shown in Fig. 1. A low voltage, 50 kV, has been chosen for the low-energy beam transport to simplify the high-voltage installation. Two solenoids suffice to focus a rotationally symmetrical beam into the rotationally symmetric transverse RFQ acceptance.

The high-voltage beam transport is at 520 keV, the injection energy of the CERN Linac I. The construction of the first Alvarez tank (separate vacuum vessel around the actual rf structure, and no quadrupole in the first half-drift-tube) is an inconvenient arrangement for the RFQ, which normally should be brought within a distance of a few centimeters of the rf structure. This being impossible, a 520-keV transport line, comprising three quadrupoles and a buncher (or "matching cavity"), had to be designed.

The rf power is fed directly into one of the RFQ's intervane spaces. Movable bulk tuners in all four quadrants insure the tuning. The vane modulation has been computed and they are being machined at Los Alamos.

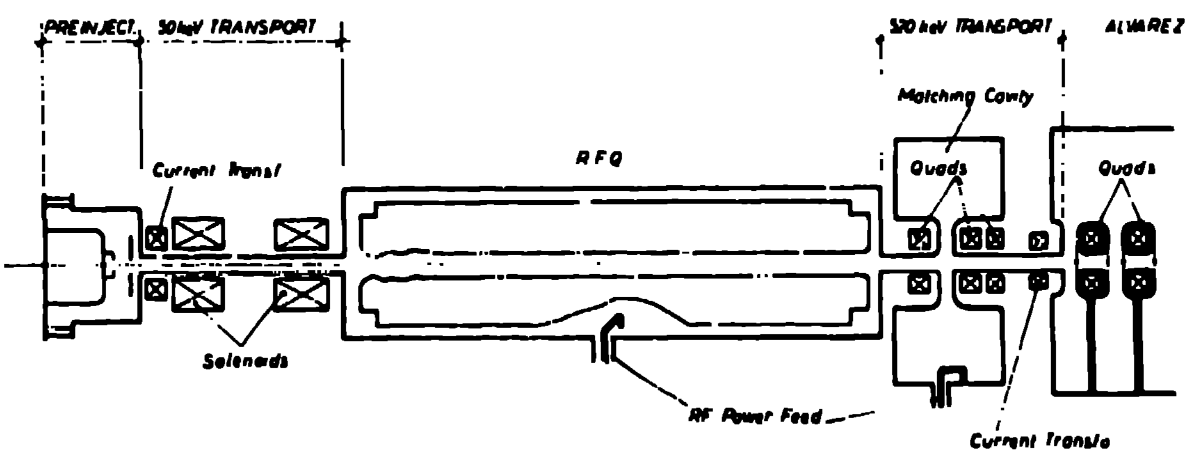

Fig. 1. Schematic layout.

*Work performed under the auspices of the US Department of Energy and CERN.

No steering elements are included in the setup. The RFQ and the 520-keV beam transport will be aligned on the Alvarez tank. The steering will be achieved by mechanical adjustment of the source and the 50-keV transport before mounting them on the RFQ.

RFQ

The CERN RFQ has to be installed on an existing Alvarez linear accelerator; hence, some constraints are put on the choice of parameters. The RFQ should be designed for a 202.56-MHz frequency, a 520-keV output energy, and an ~100-mA beam intensity. Furthermore, the RFQ should give a high capture efficiency, a limited emittance growth, and reliable operation. The design, proposed by Los Alamos, follows the usual concept of dividing the RFQ in sections; because of the relatively low final energy, the last (accelerating) section has been omitted, so that only the radial matching section, the shaper, and the gentle buncher remain.

Precautions must be taken with respect to maximum electric fields in the RFQ. To compute the enhancement of the electric field caused by vane modulation, a special computer program has been developed capable of treating three-dimensional field problems. With the condition that $E_{max} < 1.75$ times the Kilpatrick limit (~25.7 MV/m), the parameters given in Table I have been established for the CERN RFQ.

Beam Transport and Matching

Preinjector and 50-keV Transport: A CERN duoplasmatron ion source, slightly modified, is used with a 50-kV dc accelerating column. The three-electrode column also provides some focusing and screening against backstreaming electrons.

Because the beam is rotationally symmetrical at the column output, and should be so at the RFQ input, quadrupole lenses were found to be inconvenient for this region. The high beam intensity also made the use of electrostatic lenses impractical; finally, solenoids were chosen. The high fields compelled one to treat iron saturation, in addition to aberration problems. A compromise design resulted in a pulsed solenoid with laminated-iron return yoke; the central field on axis approaches 1 T, the effective length being ~10 cm. Figure 2 shows the beam evolution from the ion source to the RFQ.

The 520-keV Transport: Three quadrupoles and a matching cavity are necessary to bring an acceptable beam into the Alvarez. In the Alvarez, the first four quadrupoles complete the transverse matching, so that the beam is matched into the linac's transverse acceptance from the fifth cell onwards (see Fig. 3). Longitudinally, we cannot avoid a slight mismatch; this mismatch probably will not be too harmful. Furthermore, the relatively large distances between the tanks of the Linac I constitute other unavoidable sources of longitudinal mismatch. For the moment, some beam losses will be tolerated in Tank 1, because the required gradients for the first and third quadrupoles (73 and 60 T/m, respectively) are out of reach of the present magnets.

The rf Aspects

Two models have been built for the experimental study of the tuning process: a rough approximately half-scale mock-up, and a one-to-one model of high precision and rigidity (Fig. 4A). Tests have been done on the latter, with a single unmodulated vane isolated by a roof-shaped shield at the symmetry planes of the quadrupole mode (Fig. 4B).

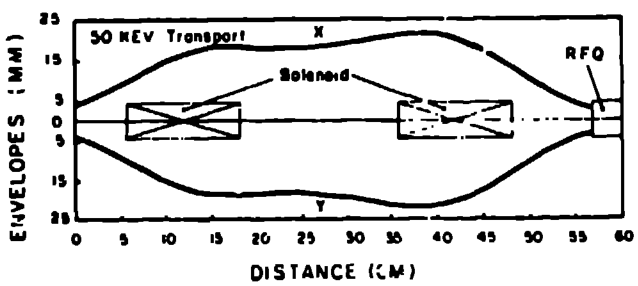

Fig. 2. Beam envelopes for 50-keV beam transport.

TABLE I

CERN RFQ

Ion: proton					
Frequency: 202.56 MHz	W(MeV)	0.050	0.050	0.075	0.520
	E_s(MV/m)	5.0	24.9	24.9	24.9
PARMTEQ RESULTS	m	1.00	1.00	1.129	2.152
Input current: 100 mA	a(mm)	29.0	6.78	6.40	4.21
Output current: 89 mA	r_0(mm)	29.0	6.78	6.78	6.78
Input (90): 0.068	ϕ_s(deg)	--	-90.0	-73.1	-30.0
Output (90): 0.20	E_0(MV/m)	0	0	0.50	2.56
Input (rms): 0.017	V(kV)	108	108	108	108
Output (rms): 0.043	B	5.5	5.5	5.5	5.5
	L(cm)	0	3.1	63.7	138.2

[a]The emittances are normalized values and are to be multiplied by π to obtain the ellipse area in cm-mrad units.

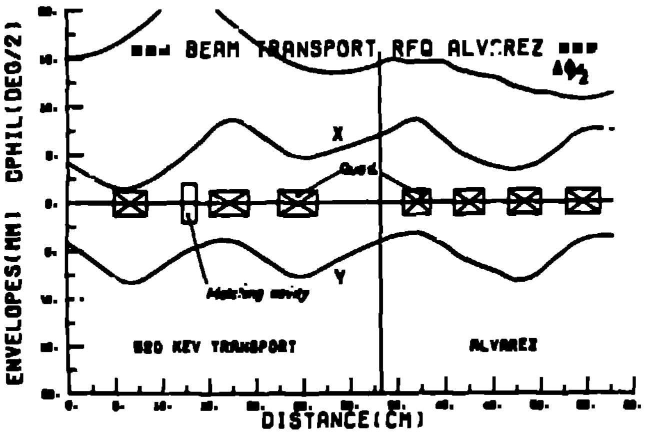

Fig. 3. Beam at injection into Alvarez.

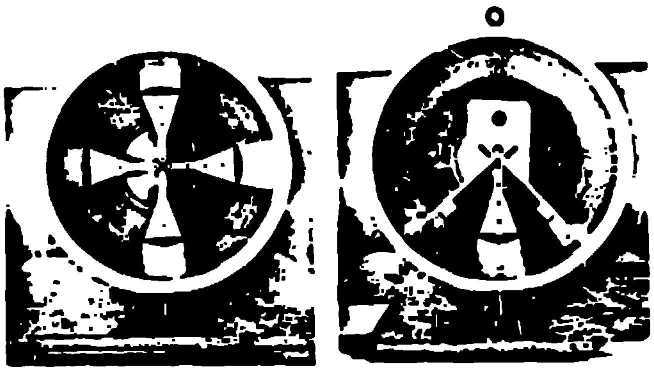

Fig. 4. Full-scale model a) with four vanes mounted b) with single isolated vane.

Let ϕ_1, ϕ_2, and ϕ_m represent the axial magnetic flux (or interchangeably, a transverse electric field quantity) at Ends 1, 2, and in the center of the vane section. If the relative loading of the two end cells is modified so that the overall resonant frequency remains constant, the linear tilt (ϕ_1/ϕ_2) can be set to any arbitrary value; however, the nonlinear term $[2\phi_m/(\phi_1 + \phi_2)-1]$--that is, the relative field deviation from linearity in the middle--remains essentially unchanged. Repeating the test at different frequencies, and with different end-cell geometries, leads to curves such as Fig. 5: the nonlinear term is zero only at a particular frequency, which depends slightly on the shape of the end cell. Operating above this frequency leads to increasingly convex longitudinal field distributions; operating below this frequency leads to increasingly concave shapes.

This behavior can be intepreted as the combined action of two effects.

- A solely vane-dependent part determines a unique frequency for the zero of the nonlinear term, and its slope, in this region. This frequency is the cutoff, or zero-order frequency of the vane geometry and may be calculated by codes such as "SUPERFISH." The slope reflects the structure's reaction to detuning and associated reactive-power transfer.
- A higher mode part accounts for differences in the field pattern of the intervane space and the end pieces. The higher modes, created at the ends, tend to reinforce, or to cancel, the already existing nonlinearity and cause the observed frequency spread for vanishing nonlinearities around the unique cutoff frequency.

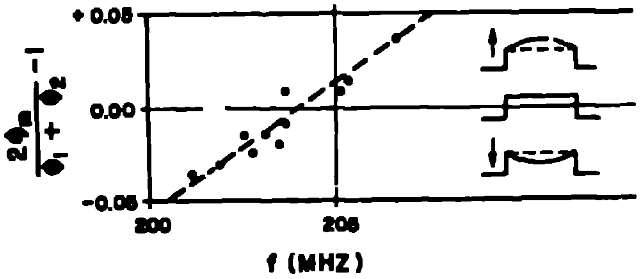

Fig. 5. Nonlinear term versus frequency.

The RFQ will be tuned as follows.

- The end cells are permanently tuned by movable or exchangeable inserts in a cutout at the base of the vane ends. The distance of the cavity endplate from the vane tips is 10 to 15 mm; at that distance, the influence on the tuning is minimal.
- In the vane region, each quadrant contains two bulk tuners (a total of 8) that are adjustable during operation. Two rows of five diagnostic holes per quadrant, vacuum sealed by glass tubes, will permit continuous monitoring.

The rf power will be fed directly, by a single loop, into one quadrant; however, additional flanges are provided to feed each quadrant, if necessary. Despite its many attractive features, the rf manifold has not been included in the design; the relatively large outer diameter of the cavity did not permit a sufficiently wide manifold to be added, without danger of running into circumferential mode problems.

Mechanical Engineering and Vacuum

The RFQ cavity and vanes are made of mild steel, electrolytically copper plated. The vanes are supported at three points inside the cavity, so that they can be aligned without introducing deformations in either the cavity wall or in the vanes.

The whole assembly, from preinjector to the matching cavity, is mounted on a common underframe; this frame is supported at three points by low-rate flexible springs to remove a large portion of the bending moment from the existing Alvarez tank on which the RFQ structure must be rigidly fixed.

Cavity-vane connections, both electrical and thermal, are made by using flexible copper strips that are welded after vane assembly, before final alignment and initial rf tuning. The whole structure is water cooled through tubes glued to both main flanges of the cavity.

The nominal pressure throughout the system is 10^{-7} torr. The preinjector is equipped with two turbomolecular pumps of 500 ℓ/s, the cavity with three ion pumps of 500 ℓ/s, and one turbomolecular pump for roughing. Aluminum seals are used on all joints except on the preinjector, where rubber seals are used.

Status and Outlook

The parameters have been frozen; some components have been ordered, and a few have been delivered. Beam measurements are expected to begin later this year: first using only the ion source and the 50-kV extraction, and later with the solenoids in place. We plan to have the beam measurements at the 520-keV level finished by May 1982, so that the beam can be obtained from Linac I by July 1982.

Because it may turn out that alpha beams are requested from Linac I for ISR operation, it is imperative to allow for quick disassembly of the RFQ and for reinstallation of the Cockcroft-Walton. Later requests for alpha beams, or other light ions, may require another RFQ injector with a quick changeover facility for different particles.

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